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Final Technical Report
January 1978

QUANTIFICATION OF PRINTED CIRCUIT BOARD (PCB) CONNECTOR RELIABILITY

George F. Guth

Martin Marietta Corporation

Approved for public release; distribution unlimited.

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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Martin Marietta Corporation conducted a 12-month program to develop a failure rate mathematical model for printed circuit board connectors as used in military electronic equipment and conforming to the requirements of MIL-C-21097 and MIL-C-55302. This model is provided in the format of a subsection to Section 2.11 of MIL-HDBK-217B, and includes the model, instructions for its use, and limitations in its use. More than 736 million part-hours of operating field data were collected from industrial and Government data sources. Data was analyzed manually and sorted by computer.

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Conclusions are summarized in the revised base failure rates and mathematical models described. Failure rates show a significant decrease from the present rates described in MIL-HDBK-217B. The mathematical model is described with a multiplying cyclic parameter (Π_K) which varies in accordance with mating/unmating cycles of each connector.

(PI sub K)

SUMMARY

The reliability of printed circuit board (PCB) electrical connectors was studied from September 1976 to September 1977. Major objectives of the study were to quantify reliability and develop failure rate mathematical models for PCB connectors for inclusion in MIL-HDBK-217B. Connectors studied were specified in MIL-C-21097 (one-piece connector) and MIL-C-55302 (two-piece connector).

The study was initiated by mailing a survey questionnaire to industrial and Government facilities, followed by telephone contact with questionnaire respondents and personal visits to facilities having the most favorable data response. Simultaneously, in-house equipment data and library data were reviewed. All data collected were programmed into a computer for sorting and were then analyzed manually.

The collected PCB connector data were grouped, analyzed, and tested for homogeneity before being combined. A 60 percent confidence limit was calculated for all data under evaluation. Complete component type listings were assembled on data used to generate the operating failure rates for MIL-HDBK-217B.

More than 736 million part hours of operating data were collected in this study. The data cover the PCB connectors in ground-fixed, naval-sheltered, and airborne environments. A failure rate mathematical model and revised base failure rates were also developed for the PCB connectors.

PREFACE

This Final Technical Report on Quantification of Printed Circuit Board Connector Reliability was prepared for Rome Air Development Center, Griffiss Air Force Base, New York by the Product Support Engineering Laboratory of the Martin Marietta Corporation, Orlando Division, under Contract F30602-76-C-0439. The major objectives of the study were to quantify the reliability of printed circuit board connectors through collection and analysis of operational field data, and to develop a failure rate mathematical model to be included as a new subsection in MIL-HDBK-217B.

The contract was issued on 27 September 1976 by Rome Air Development Center (RADC). Mr. John McCormick (RBRM) was the RADC Project Engineer. The period of contract performance was 27 September 1976 to 27 September 1977.

Technical consultation and assistance in the acquisition of data was provided by Messrs. Edwin Kimball, Donald Cottrell, William Maynard, Edward French, Thomas Kirejczyk, Thomas Gagnier, and Bradley Olson. In addition, other Martin Marietta study team members were Messrs. Aaron Penkacik, Robert Whalen, and Thomas Young, and Mmes. Lynn Westling, Lynn Mercer, and Betty Jean Thomas.

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EVALUATION

This effort supports RADC TPO R-5-B, Reliability. Appendix B of the report, which includes a prediction model and updated PCB connector base failure rates, has been submitted to RADC/RBRT, the Preparing Activity (PA) for MIL-HDBK-217B, Reliability Prediction of Electronic Equipment, for inclusion in the next revision of the Handbook. Use of this revised and updated model and updated base failure rates will greatly improve the accuracy of PCB connector reliability predictions, bringing them in line with the actual reliability of PCB connectors being used in today's weapons systems.

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SECTION I

INTRODUCTION

MIL-HDBK-217B, "Reliability Prediction of Electronic Equipment," provides a single mathematical model for calculating the failure rate of all connector types, including both one- and two-piece printed circuit board (PCB) connectors. The many differences of PCB connectors compared to multi-pin connectors (circular, rack, panel, etc.) cause concern over adequacy of the present model.

The purpose of contract number F30602-76-C-0439 was to formulate a mathematical model that could provide the capability to predict failure rate for both one- and two-piece PCB connectors. This model has been constructed and validated. It will allow reliability assessment of PCB connectors based on pin complexity, application, stresses, operational environment, and other significant factors. This report details results of the contractual effort by discussing the data collected for the PCB connectors, the methodology for data analysis and modeling, and gives the assumptions and procedures followed for constructing PCB connector reliability prediction models suitable for incorporation into a subsection of Section 2.11 of MIL-HDBK-217B.

SECTION II

DATA COLLECTION

2.1 Literature Review

Data for operating failure rates have been collected from contractors, institutions, and Government agencies. A comprehensive literature review was also made to obtain information and pertinent data on PCB connectors. Martin Marietta's Technical Information Center (TIC) was researched for up-to-date information on PCB connectors. A bibliography, constructed using key words, was reviewed for applicability. Data sources used in this computer search included Martin Marietta in-house documents and documents listed by other documentation centers such as the Defense Documentation Center (DDC), NASA Scientific and Aerospace Reports (STAR), and National Technical Information Services (NTIS).

2.2 Data Source Contacts

The first action upon contract initiation was generation of a list of potential data sources. This list was developed from sources used in previous study contracts and from Government-Industry Data Exchange Program (GIDEP) memberships. Other suggested sources resulted from consultations with RADC. A total of 560 companies or agencies were on the mailing list for the data survey letter. Of these, answers were received from about 260 companies. Every survey sheet returned was carefully scrutinized to determine whether available data would be useful to this study. Each respondent to the survey was contacted by telephone to further detail the amount and type of reliability information that might be available. Where possible, data were mailed directly to Martin Marietta Corporation. In areas where a large amount of data retrieval was potentially available, personal visits were arranged to visit the data sources, review the operational data, reduce the data where necessary, and return the pertinent data to Martin Marietta for further analysis. A total of 47 data sources were visited, with trips to the Northeast, Midwest, Los Angeles, San Francisco, the Southwest. The trips resulted in accumulation of the majority of data.

A summary of data sources contributing to this study program appears in Appendix A.

SECTION III

PCB CONNECTORS

PCB connector failure mode and mechanism data and design note information were obtained from visits to component users, as well as from literature available for study. The objective of this study was to identify problem areas, and where possible, suggest methods to improve reliability in PCB connectors.

3.1 One-Piece PCB Connectors

The *one-piece PCB connector*, also known as a *card edge connector*, conforms to MIL-C-21097 (Military Specification, General Specification for Connectors, Electrical, Printed Wiring Board, General Purpose). It is a receptacle containing stamped or formed contacts designed to be used with a plug that consists of printed contact tabs that are a part of the printed wiring board conductor pattern (Figure 1). This type of connector is the most popular rigid-board connector type.

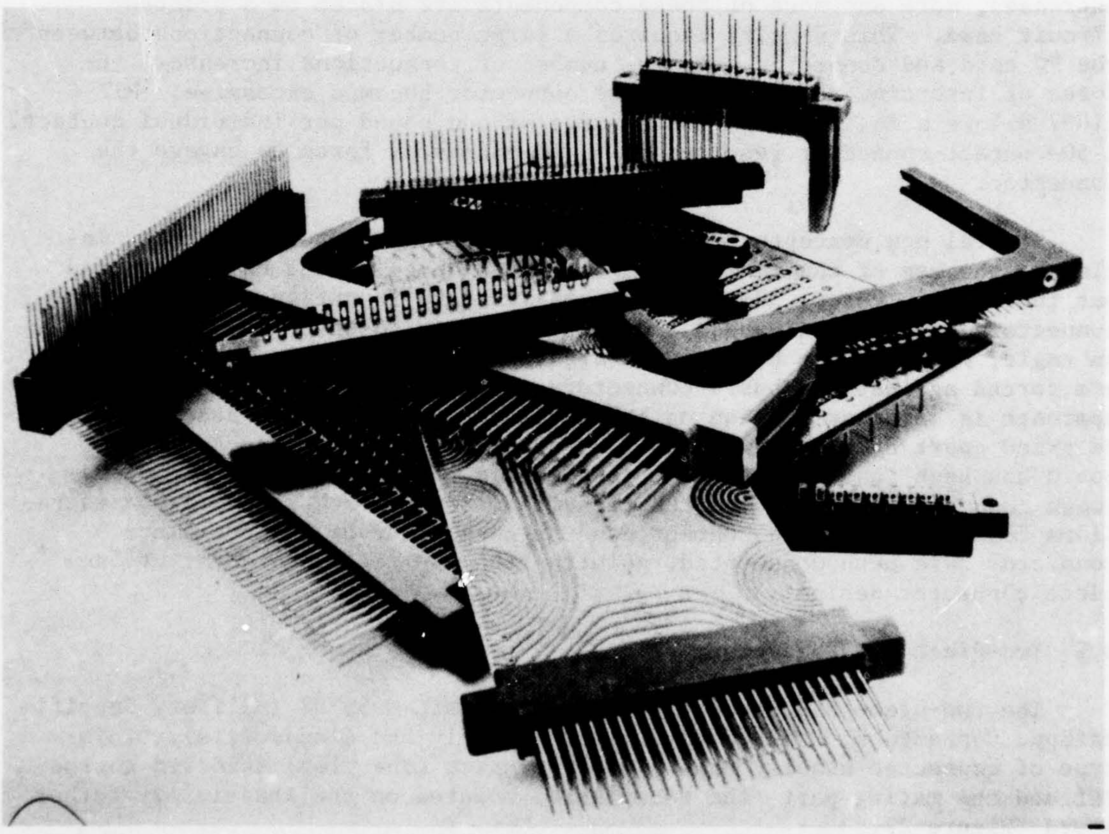

Figure 1. One-Piece Connectors

The edge-mounted connector is subdivided into three types:

- Type A - Single-Circuit Connector (opposing contacts parallel connected within the connector)
- Type AD - Double-Circuit Connector (opposing contacts electrically isolated from each other)
- Type C - (connector assembly consisting of a male adapter mating with a connector receptacle).

Contact spacing ranges from 0.05 inch on AD-type connectors to 2 inches on C-type connectors. Board thickness designations are from 1/8 inch to 1/16 inch boards.

One-piece connectors are polarized with a keyway in the board and a key in the receptacle, or by molding card guides of different lengths on each end. The only significant restriction in the use of the one-piece connector is contact density. As the packaging of electronic equipment becomes more and more dense and the reliability of integrated circuits increases, more and more of these components are placed on a printed circuit card. This density requires a large number of connections between the PC card and connector. As the number of connections increases, the force of inserting the card into the connector becomes excessive. MIL-C-21097 allows a maximum engagement force of one pound per individual contact. A 50-contact connector requires up to 50 pounds of force to engage the connector.

Several new concepts have been advanced by connector designers, including the use of chamfers and bevels on the edge of the card to spread out the push-in force. Several designs for Zero Insertion Force (ZIF) connectors have been advanced. One technique is to enter the board at an angle, and when the board is straightened and locked in, the contacts are forced against the board connectors to make firm connections. Another approach is using cam action on the connector. Connector contacts would be pried apart by a cam prior to insertion of the PC board. After the board has been inserted, the cam is released to provide firm contact between connector contacts and PCB circuits. Several other design considerations for increasing the contact density capability of the one-piece connector have been documented, pointing the way for improvement of one-piece connector design.

3.2 Two-Piece PCB Connectors

The two-piece PCB connector conforms to MIL-C-55302 (Military Specification, Connectors, Printed Circuit Subassembly and Accessories). This type of connector usually consists of one part (the plug) soldered to the PCB and the mating part (the receptacle) mounted on the chassis or another board (Figure 2).

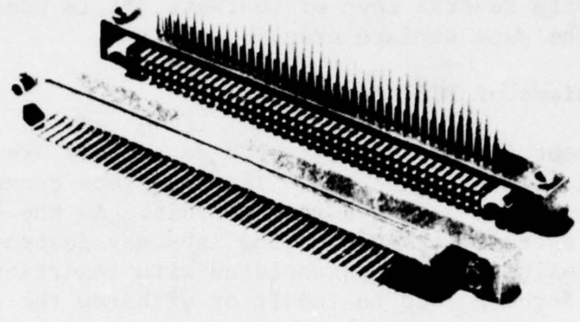

Figure 2. Two-Piece Connector

The two-piece connector is subdivided into two principal types:

- Contact spacing ranging from 0.075 inch to 0.200 inch, and pin densities varying from 7 to 180 per connector.

- Polarization of the connector using guide pins of greater length than the contacts or offsetting rows of contacts to eliminate symmetry.

3.3 Comparison of One- and Two-Piece Connectors

At the present time, the one-piece connector is not approved for use in airborne Air Force equipment. MIL-E-5400 prohibits the use of the one-piece connector in airborne equipment. A major factor affecting the reliability of the one-piece connector is divided responsibility in manufacture. A detailed specification, (MIL-C-21097) controls the production of the receptacle. This part is made by a connector manufacturer to an established quality control program. On the other hand, PCB's are produced in another area and are made specifically to a customer's order. It is very difficult to maintain rigid quality control over the product, which is needed to assure a reliable connector component.

The two-piece connector, using mating pairs of plugs and receptacles, is produced by the same manufacturer to the same established quality control program. Thus, both portions of the mated connector are maintained at a quality control level that can assure a more reliable connection.

Two-piece connectors are more expensive than one-piece designs due to higher initial costs and higher assembly costs. The plug must be secured to the PCB using auxiliary fastening devices to secure the plug to the board. This method prevents the dip-soldered contact connection from needing to provide both electrical continuity and mechanical support against torsional-shear forces during mating.

Two-piece connectors presently maintain an advantage in contact density capability. With several rows of contacts, it is possible to include more circuitry in the same surface area.

3.4 Failure Mechanisms of PCB Connectors

The most frequent failure modes of PCB connectors are associated with mating and unmating of the connectors. The one-piece connector may sustain damage to the contact tabs during a mating cycle. As the connector is inserted or removed, extreme stresses on the tabs may destroy a contact connection. Another failure mode is associated with insertion and withdrawal forces. Excessive force needed to insert or withdraw the connector can damage the connector contacts.

Moisture condensation trapped in the one-piece connector receptacle can result in corrosion or leakage problems. Corrosion necessarily leads to a high resistance or open circuit.

The two-piece connector can fail due to a bent pin caused by misalignment of pins prior to insertion.

Each of these failure modes can be reduced or eliminated by proper design, use, and application of the connector. The new ZIF designs will eliminate many of the problems associated with insertion and withdrawal forces.

SECTION IV

DATA ANALYSIS

4.1 Statistical Methods, Assumptions, and Ground Rules

Data have been collected on two types of PCB connectors conforming to MIL-C-55302 and MIL-C-21097. The data have been analyzed and summarized in the form of a failure rate for PCB connectors. Several basic ground rules and assumptions were used in this analysis and defined the statistical tests used in combining the data. The methods used for calculating failure rates at a given confidence level are presented in this section, along with numerical examples for statistical tests and calculation of failure rates.

All failure rates were calculated at the upper single-sided 60 percent confidence level. Before calculating the failure rates, component data were identified as either time- or failure-truncated. As far as could be determined, no failure-truncated data were received. All data were consequently assumed to be time-truncated. The upper confidence level failure rate was calculated by using the component part hours and the 40 percent chi-squared value at 2r + 2 degrees of freedom. If the data had been failure-truncated, the value would be obtained at 2r degrees of freedom. The general equation used for calculating the failure rate was obtained from Reference 1:

$$\frac{\chi^2\ (\alpha,\ 2r + 2)}{2T} = \text{Upper single-sided confidence level,}$$

where r = the number of failures which determines the degree of freedom coordinate used in determining chi-square (χ^2)

2r + 2 = Total degrees of freedom

α = Acceptable risk of error (40 percent in this study)

$1 - \alpha$ = Confidence level (60 percent in this study)

T = Total number of component part hours.

As an example, one failure during 88.339×10^6 part hours of ground-fixed operation were used in calculating the failure rate at the upper single-sided 60 percent confidence level on one-piece PCB connectors (MIL-C-21097). A table from Reference 1 was used as the source for the chi-squared value, with these results:

$$\text{Failure rate (60 percent confidence)} = \frac{\chi^2\ (0.40,\ 4)}{2T} = \frac{4.04}{176.678 \times 10^6}$$

$$\text{Failure rate (60 percent confidence)} = 0.022 \text{ failures}/10^6 \text{ part hours.}$$

---

1. Hald, A., "Statistical Tables and Formulas," John Wiley and Sons, Inc., New York, 1952.

4.2 Part Classes and Failure Rates

To revise Section 2.11 of MIL-HDBK-217B through development of a subsection on PCB connectors conforming to MIL-C-55302 and MIL-C-21097, field operational data and information on printed circuit board connectors were collected, studied, analyzed, and categorized by specific connector type and environmental application. Results are presented in Table 1. No PCB connectors were tested to obtain data. Instead, a rather extensive data survey and collection effort was undertaken to locate and obtain necessary data. The connectors studied were typical of those used in performing interconnection functions in military ground, airborne, satellite, ground mobile, and shipboard applications.

TABLE 1

Summary of Operating Data Collected by Component Type and Environment

Part Type	Environment	Failures	Part-Hours ($x10^{-6}$)	Operating Failure Rates	
				Point Estimate	60% Confidence
Connector (MIL-C-21097)	Ground Fixed	1	88.339	0.0113×10^{-6}	0.022×10^{-6}
Connector (MIL-C-55302)	Ground Fixed	1	23.154	0.043×10^{-6}	0.087×10^{-6}
Connector (MIL-C-55302)	Naval Sheltered	1	538.522	0.0018×10^{-6}	0.0038×10^{-6}
Connector (MIL-C-55302)	Airborne Uninhabited_T	1	33.79	0.029×10^{-6}	0.0598×10^{-6}
Connector (MIL-C-55302)	Airborne Inhabited_T	1	5.872	0.17×10^{-6}	0.344×10^{-6}
Connector (MIL-C-21097)	Ground Mobile	0	36.74	---	0.025×10^{-6}
Connector (MIL-C-55302)	Space Flight	0	10.4	---	0.087×10^{-6}

The data listed are in the form of failures per million hours and were calculated at the point estimate where failures had occurred and at the 60 percent upper confidence level for all categories.

Failure rates were not calculated when less than 1.0 million part hours of data were collected. The environmental abbreviations are the same as in MIL-HDBK-217B, except for airborne values, where an additional letter designation has been added. The subscript "T" on the airborne abbreviations designates data generated in subsonic type aircraft, such as transport and cargo planes, while the subscript "F" refers to supersonic aircraft such as fighters and interceptors.

Component failure is defined as the inability of the part to properly perform its intended function, resulting in its repair or replacement. Whenever detailed failure information was available, all secondary failures, premature removals, and procedural and personnel errors were censored. Since most data obtained only listed quantity of failures and experience with no elaboration of failure modes and mechanisms, much of these data depend on the source's ability to properly categorize their equipment failures. As a result of direct contact with most of the sources, the majority of data contributed to this study appear to have been properly screened by the contributors.

SECTION V

FAILURE RATE MODELS

Failure rate models for PCB connectors as described in Section 2.11 of MIL-HDBK-217B were reviewed with respect to the operating failure rates derived from field data collected during the study. Many variations were found to exist between failure rates derived from Section 2.11 of MIL-HDBK-217B and those derived from the operating field data. In all cases, the operating field failure rates were lower than those of MIL-HDBK-217B. Examination of the data indicated the source of the variation to be the base failure rate λ_b. An analysis was then conducted to update λ_b with the most recent data.

5.1 PCB Connector Base Failure Rate (λ_b) Evaluation

Failure rates were calculated for PCB connectors in each environment for which sufficient data had been collected. The operating failure rates for each set of data were calculated at point estimates (where failures had occurred) and at the upper 60 percent confidence level in every case. Results of these calculations are listed in Table 1. Failure rates calculated at the 60 percent confidence level were used for all further comparisons and computations.

The present mathematical model for predicted failure rate of a PCB connector, as shown in Section 2.11 of MIL-HDBK-217B, is:

$$\lambda_P = \lambda_b (\pi_E \times \pi_P) + N\lambda_{cyc}$$

where λ_b = base failure rate
π_E = environmental factor
π_P = pin density factor
N = number of pins
λ_{cyc} = cycling rate factor.

Using this equation and substituting parameters from operating field data, a typical failure rate was calculated for a MIL-C-55302 PCB connector used in a ground fixed environment with a cycling rate of 5 per 1000 hours. Ambient temperature was 45°C. The number of active pins used in this set of connectors is 98.

From MIL-HDBK-217B:

π_E = 4.0 (for ground fixed environment)
π_P = 23.5 (for 98 active pins)
$\lambda_b = 0.015 \times 10^{-6}$ (for type B insert material at $50^{\circ}C$)
λ_{cyc} = 0 (for cycling rates <40 cycles/1000 hours)

Substituting in the equation, λ_P is determined to be:

$$\lambda_P = 0.015 \times 10^{-6} (4 \times 23.5) + 98(0) = 1.41 \times 10^{-6} \text{ failures/hour.}$$

This value for λ_p is the predicted failure rate for the given PCB connector.

Failure rates were calculated in the same manner for each of the categories of connectors listed in Table 1. Each of the predicted failure rates is shown in Table 2. In each case, comparing the predicted failure rate to the observed failure rate showed that the observed field failure rate was less than the predicted failure rate from MIL-HDBK-217B. These comparisons are shown in Table 3, which indicates improvement in failure rates ranging from 4.7 to 132.

TABLE 2

MIL-HDBK-217B Predicted Failure Rates

Environment	Predicted Failure Rate (Failures/10^6 Hours)	
	MIL-C-21097	MIL-C-55302
Ground Fixed	0.399	1.41
Naval Sheltered	---	0.0501
Airborne Uninhabited$_T$	---	1.49
Airborne Inhabited$_T$	---	1.62
Ground Mobile	1.226	---

TABLE 3

Predicted/Observed Failure Rate Ratio

Environment	Predicted/Observed Failure Rate Ratio	
	MIL-C-21097	MIL-C-55302
Ground Fixed	18.13	16.2
Naval Sheltered	---	132.0
Airborne Uninhabited$_T$	---	25.0
Airborne Inhabited$_T$	---	4.7
Ground Mobile	49	---

The demonstrated improvement in reliability of each set of connectors implied the base failure rate has improved by some factor. Using the ground fixed environment as a normalizing value, the initial reduction factor was selected to be 16. Thus, the scaling factor A in the base failure rate equation, $\lambda_b = Ae^x$ was reduced from 6.9 to 0.431.

5.2 PCB Connector Cycling Factor (π_K) Evaluation

PCB connectors are subjected to stress and wear with each mating or unmating of the connector. These conditions relate directly to the failure rate of the connector.

In the present mathematical model for PCB connectors in Section 2.11 of MIL-HDBK-217B, the failure rate due to mating and unmating of a PCB connector is added to the connector failure rate and is dependent on the cycling rate and number of active pins in the connector. This cycling failure rate is described as:

$$\lambda_{cyc} = 0.001\ e^{(f/100)}$$

where f is the cycling rate in cycles/1000 hours (Table 4). This factor is ignored for connectors experiencing cycling rates $\leq$ 40 cycles/1000 hours.

Evaluation of cycling data (Reference 2) on all types of connectors showed a definite relationship between cycles of mating and unmating and the type of environmental usage of the connector in the space flight environment, an assumption of one connection was made, and a multiplier factor for cycling of PCB connectors was developed. This was called π_K. The base factor π_K for space flight was set to 1. Table 5 indicates the frequency of mating/unmating cycles determined from the evaluation of cycling data. The frequency of cycling connectors increases from 0 in space flight to once every 20 operating hours for airborne equipment. Evaluation of the predicted failure rates (reduced by 16) indicates a range of from 1.0 to 4.0 for π_K. This was determined from observation of the cycling rate of the connectors and the effects on the predicted failure rate. Table 6 lists the π_K factors derived in terms of mating cycles/1000 hours. The new factor includes all cycling rates with none ignored. From 0 mating cycles to one every 20,000 operating hours, the factor π_K is 1.0 and does not affect the base failure rate. Between one cycle every 20,000 operating hours and one cycle every 2000 hours, π_K becomes 1.5 and increases the base failure rate. Between one cycle every 2000 hours and one cycle every 200 hours, the factor increases to 2. π_K becomes 3.0 from one cycle every 200 hours to one cycle every 20 hours. For frequencies above one cycle every 20 hours, the π_K factor is 4.0.

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2. Plein, K. M., Funk, J. R., and James, L. E. "Reliability Study Circular Electrical Connectors," Hughes Aircraft Company, June 1973.

TABLE 4

Cycling Failure Rate Versus
Cycling Rate from Existing
MIL-HDBK-217B

f	λ_c	f	λ_c
10	0.0011	260	0.0135
20	0.0012	270	0.0149
30	0.0013	280	0.0164
40	0.0015	290	0.0182
50	0.0016	300	0.0201
60	0.0018	310	0.0222
70	0.0020	320	0.0245
80	0.0022	330	0.0271
90	0.0025	340	0.0300
100	0.0027	350	0.0331
110	0.0030	360	0.0366
120	0.0033	370	0.0404
130	0.0037	380	0.0447
140	0.0041	390	0.0494
150	0.0045	400	0.0546
160	0.0050	410	0.0603
170	0.0055	420	0.0667
180	0.0060	430	0.0737
190	0.0067	440	0.0815
200	0.0074	450	0.0900
210	0.0082	460	0.0995
220	0.0090	470	0.1099
230	0.0100	480	0.1215
240	0.0110	490	0.1343
250	0.0122	500	0.1484

Note: $\lambda_c = 0.001\, e^{(f/100)}$

where λ_c is failures/ million hours and f is cycling rate in cycles/ 1000 hours.

TABLE 5

Connector Mating Frequency in
Several Environments

Environment	Hours/Mating
Space Flight	No Mating/Unmating
Naval	2000
Ground	200
Airborne	20

TABLE 6

Derived π_K Factors

Mating Cycles (Matings/1000 Hours)	π_K
0 - 0.05	1
0.05 - 0.5	1.5
0.5 - 5.0	2.0
5.0 - 50.0	3.0
>50	4.0

5.3 PCB Connector Pin Density Factor (π_P) Evaluation

π_P is determined in MIL-HDBK-217B as a factor increasing exponentially due to the increase in active pins in a connector. π_P modifies the base failure rate. The equation to determine π_P is:

$$\pi_P = e^{\left(\frac{N-1}{N_o}\right)^q}$$

where: $N_o = 10$
$q = 0.51064$
N = number of active pins.

π_P was evaluated with respect to its contribution to the total failure rate prediction and found not to be substantially changed. The value of π_P in the base model is valid and remains unchanged.

5.4 Reevaluation of λ_b Due to Model Changes

In Section 5.1, the value of the constant A was reduced by a factor of 16 to bring the predicted failure rate model in line with observed values. The model calculated at that time used an additive cycling modifier, N λ_{cyc} to determine the effects of the mating and unmating the connector. Since the π_K factor to be used in the new model is multiplicative, it directly affects the base failure rate of the connector:

$$\lambda_P = \lambda_b \, (\pi_E \times \pi_P \times \pi_K)$$

An evaluation of the same group of data calculated in Section 5.1 results in a new failure rate:

$$\pi_E = 4.0$$
$$\pi_P = 23.5$$
$$\pi_K = 2.0$$
$$\lambda_b = 0.00094 \times 10^{-6}$$

$$\lambda_P = 0.176 \times 10^{-6} \text{ failures/hour}$$

Results of calculations for each group of connectors using the new failure rate mathematical model are shown in Table 7. Observation of the data indicates the predicted to observed failure rates are high by at least a factor of two. Reduction of the base failure rate by this factor results in an overall reduction in the constant A of 32. A then becomes 0.216. Base failure rates are shown in Table 8 as compared to present base failure rates in MIL-HDBK-217B. Table 9 lists the comparison of observed failure rates with the predicted failure rates derived with the new model.

TABLE 7

Failure Rate Comparison with Uncorrected Model

Environment	Observed Failure Rate	Proposed Model
Ground Fixed (MIL-C-21097)	0.022	0.050
Ground Fixed (MIL-C-55302)	0.087	0.176
Naval Sheltered (MIL-C-55302)	0.0038	0.112
Airborne Uninhabited (MIL-C-55302)	0.0598	0.33
Airborne Inhabited (MIL-C-55302)	0.344	0.366
Ground Mobile (MIL-C-21097)	0.025	0.154

TABLE 8

Base Failure Rate

Temp (^{o}C)	Present MIL-HDBK-217B	Proposed
0	0.004	0.000125
10	0.005	0.00016
20	0.007	0.0002
30	0.009	0.0003
40	0.012	0.0004
50	0.015	0.0005
60	0.019	0.0006
70	0.024	0.0008
80	0.030	0.0009
90	0.037	0.0012
100	0.046	0.0014
110	0.058	0.0018
120	0.072	0.0022
130	0.089	0.0028
140	0.111	0.0034
150	0.139	0.004
160	0.175	0.005
170	0.221	0.007
180	0.281	0.009
190	0.359	0.011
200	0.463	0.014

TABLE 9

Model Improvement by Factor Reduction

Environment	Observed Failure Rate	Proposed Model
Ground Fixed (MIL-C-21097)	0.022	0.025
Ground Fixed (MIL-C-55302)	0.087	0.088
Naval Sheltered (MIL-C-55302)	0.0038	0.056
Airborne Uninhabited (MIL-C-55302)	0.0598	0.166
Airborne Inhabited (MIL-C-55302)	0.344	0.183
Ground Mobile (MIL-C-21097)	0.025	0.077

5.5 PCB Connector Environmental Factor (π_E)

Examination of the failure rates determined in the new model, using the ground fixed environment as reference, shows adjustments in the environmental factors are now required to bring some factors into line. Airborne uninhabited failure rates exhibit a 3 to 1 increase from observed to predicted. The environmental factor of 10 is too high and must be reduced by a factor of 2. Airborne inhabited rates exhibit a 2 to 1 decrease from the observed to predicted, indicating the environmental factor should be increased. Airborne inhabited π_E was set equal to airborne uninhabited π_E, indicating all airborne environments are equally severe with respect to connectors. The ground mobile environmental factor was reduced from 8 to 5 and the naval sheltered factor was reduced from 4 to 2. These adjustment values are summarized in Table 10.

The present environmental table in MIL-HDBK-217B lists an environmental factor for lower quality connectors in comparison to military type connectors. Present values showed a quality factor of 1/10 in the ground benign environment, reducing to a factor of 1/2 for the most severe environment (missile launch). Environmental factors for ground benign environments have little effect on either type connector, while factors during missile launch greatly affect those lower quality connectors. Therefore, the π_E factors for lower quality connectors have been revised for each environment to reflect more accurately the severity of the environment with regard to the connector. Table 11 lists these revisions.

The aircraft environment was expanded to four categories to separate supersonic aircraft from other types. It is generally accepted that equipment on supersonic aircraft are exposed to higher levels of shock, vibration, and acoustic noise, and to a more severe operating temperature

range than equipment on other aircraft. Mission duration is usually much shorter for supersonic aircraft. Is this study program, only data from the subsonic aircraft equipment were collected. From other studies (References 3 and 4), analyses of data have been made, and a factor of 2:1

TABLE 10

π_E Adjustment Values

Environment	π_E Proposed	π_E Present
Airborne Inhabited$_T$	5	4
Airborne Uninhabited$_T$	5	10
Ground Mobile	5	8
Naval Sheltered	2	4

TABLE 11

Environmental Factors

Environment	π_E	
	MIL SPEC	Lower Quality
G_B	1.0	1.5
S_F	1.0	1.5
G_F	4.0	8.0
N_S	4.0	8.0
A_I	5.0	15.0
A_U	5.0	15.0
G_M	5.0	15.0
N_U	9.0	19.0
A_{IT}	10.0	30.0
A_{UT}	10.0	30.0
M_L	15.0	30.0

3. Kern, G. A., and Drnas, I. M., "Operational Influences on Reliability" page 5-4, Hughes Aircraft Company, RADC-TR-76-366, December, 1976.

4. Pearce, M. B. and Rise, G. D., "Technique for Developing Equipment Failure Rate K Factors" page 13, Boeing Aerospace Company, December 1973.

for supersonic versus subsonic environmental stress was developed. This value was determined to be a good general factor to differentiate between subsonic and supersonic aircraft. The term supersonic aircraft includes fighters and interceptors, while the subsonic category encompasses transport, heavy bomber, cargo, and patrol aircraft.

5.6 PCB Connector Failure Rate Mathematical Model

The new failure rate mathematical model has been determined to be:

$$\lambda_P = \lambda_b (\pi_E \times \pi_P \times \pi_K)$$

Evaluation of failure rates using the new model and base failure rate for each category of connectors from Section 5.1 results in:

- Ground fixed (MIL-C-21097)

  $\lambda_P = \lambda_b (\pi_E \times \pi_P \times \pi_K) = 0.00033 (4.0 \times 9.5 \times 2.0)$
  $\lambda_P = 0.025 \times 10^{-6}$ failures/hour

- Ground fixed (MIL-C-55302)

  $\lambda_P = 0.00047 (4.0 \times 23.5 \times 2.0)$
  $\lambda_P = 0.088 \times 10^{-6}$ failures/hour

- Naval sheltered (MIL-C-55302)

  $\lambda_P = 0.0004 (2.0 \times 23.5 \times 1.5)$
  $\lambda_P = 0.0287 \times 10^{-6}$ failures/hour

- Airborne uninhabited (MIL-C-55302)

  $\lambda_P = 0.0004 (5 \times 10.42 \times 4.0)$
  $\lambda_P = 0.083 \times 10^{-6}$ failures/hour

- Airborne inhabited (MIL-C-55302)

  $\lambda_P = 0.00047 (5 \times 24.32 \times 4.0)$
  $\lambda_P = 0.229 \times 10^{-6}$ failures/hour

- Ground mobile (MIL-C-21097)

  $\lambda_P = 0.00033 (5 \times 14.6 \times 2.0)$
  $\lambda_P = 0.048 \times 10^{-6}$ failures/hour

These failure rates are summarized in Table 12.

TABLE 12

Proposed Model Failure Rates

Environment	λ_p (Failure Rate/10^6 Hours)	
	Observed	Model
Airborne Uninhabited$_T$	0.0598	0.083
Airborne Inhabited$_T$	0.344	0.229
Ground Mobile	0.025	0.048
Naval Sheltered	0.0038	0.028
Ground Fixed (MIL-C-55302)	0.087	0.088
Ground Fixed (MIL-C-21097)	0.022	0.025

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In concluding the Quantification of Printed Circuit Board (PCB) Connector Reliability Program, Contract F30602-76-C-0439, more than 736 million part-hours have been collected from all sources. This data base has been used to prepare a failure rate mathematical model for a new Section 2.11.1 of MIL-HDBK-217B.

Some areas of data categories are not well defined. Data contributors are generally reluctant to incur large expenditures to further refine data and information that they provide free of charge. They are also hesitant to allow visitors unrestricted access to their detailed records. In many instances, records were not maintained in areas such as mating/unmating cycles of PCB connectors. The basic assumptions made have been that the collected data reflect average failure rates for parts over the general spectrum specified for and used in most military equipment.

PCB connector failure rate prediction models were defined and validated in six areas of interest. Appendix B presents these models and explains their use.

The data collected during this study were compared to the existing information in Section 2.11 of MIL-HDBK-217B. Significant increases in the average reliability have been noted for both one-piece and two-piece connectors. These data indicate that reliability growth has been taking place, and the state-of-the-art is still improving.

6.2 Recommendations

Two recommendations are submitted for consideration:

1. With the improvement in PCB connector design and the need for larger PCB connector pin capability, Section 2.11.1 of MIL-HDBK-217B should be updated every three years. Data in the next several years should reflect changes in the state-of-the-art on a timely basis.

2. Continuing efforts to collect PCB connector reliability data should be investigated. In this study, military systems contractors were found to be growing more reluctant to furnish uncontracted data free of charge. This is due to costs incurred by them to recover or reconstruct past data. Many contractors are only tracking failures to the line replaceable unit (LRU) level instead of the component level, thus reducing the amount of component data available.

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APPENDIX A

DATA SOURCES

APPENDIX A

DATA SOURCES

Aerojet
Azusa, California

Autonetics
Anaheim, California

General Electric Corporation
Syracuse, New York

Harris Corporation
Melbourne, Florida

Lear Seigler
Grand Rapids, Michigan

Litton Industries
Van Nuys, California

Reliability Analysis Center
Rome, New York

Spectra Physics
Santa Clara, California

Sperry Univac
St. Paul, Minnesota

Sperry Systems Management
Great Neck, New York

APPENDIX B

REVISED INPUTS TO SECTION
2.11, MIL-HDBK-217B

2.11.1 PRINTED CIRCUIT BOARD CONNECTOR

Specification	Description
MIL-C-21097	One-Piece Connector
MIL-C-55302	Two-Piece Connector

Part Failure Rate Model (λ_p)

The failure rate, λ_p, is for a mating pair of connectors and is:

$$\lambda_p = \lambda_b (\Pi_E \times \Pi_P \times \Pi_K) \text{ failures}/10^6 \text{ hours}$$

where the factors are:

Π_E Table 2.11.1-4

Π_P Table 2.11.1-5

Π_K Table 2.11.1-6

PRINTED CIRCUIT BOARD CONNECTOR

Table 2.11.1-1. Prediction Procedure for PCB Connectors

Base failure rate model (λ_b)

$$\lambda_b = Ae^x$$

$$\text{where } x = \left(\frac{N_T}{T+273}\right) + \left(\frac{T+273}{T_o}\right)^P$$

e = 2.718, natural logarithm
T = operating temperature (^oC)
T = ambient + temperature rise (Table 2.11.1-2)

A = 0.216
T_o = 423
P = 4.66
N_T = -2073.6

λ_b values are shown in Table 2.11.1-3.

PRINTED CIRCUIT BOARD CONNECTOR

Table 2.11.1-2. Connector Temperature Rise (^{o}C) Versus Contact Current and Contact Size

Amperes/Contact	26 GA	22 GA	20 GA
1	1.4	0.99	0.6
2	5.0	3.6	2.3
3	10.5	7.6	4.9
4	17.9	12.9	8.31
5	27.1	19.4	12.6

$\Delta T = 1.38\ (i)^{1.85}$ for 26 GA

$\Delta T = 0.989\ (i)^{1.85}$ for 22 GA

$\Delta T = 0.64\ (i)^{1.85}$ for 20 GA

Note 1: ΔT = ^{o}C temperature rise
i = amperes per contact

Note 2: The operating temperature of the connector is usually assumed to be the sum of the ambient temperature surrounding the connector plus the temperature rise generated in the contact.

PRINTED CIRCUIT BOARD CONNECTOR

Table 2.11.1-3. Operating Temperature Versus Base Failure Rate (λ_b) in Failures/Million Hours

Temperature (^oC)	λ_b
0	0.00013
10	0.00016
20	0.00021
30	0.00028
40	0.00037
50	0.00047
60	0.0006
70	0.0008
80	0.0009
90	0.0011
100	0.0014
110	0.0018
120	0.0022
130	0.0028
140	0.0035
150	0.0043
160	0.0055
170	0.007
180	0.0088
190	0.011
200	0.014

PRINTED CIRCUIT BOARD CONNECTOR

Table 2.11.1-4. π_E Based on Environmental Service

Environment	π_E	
	MIL SPEC	Lower Quality
G_B	1.0	1.5
S_F	1.0	1.5
G_F	4.0	8.0
N_S	4.0	8.0
A_{IT}	5.0	10.0
A_{UT}	5.0	10.0
G_M	5.0	10.0
N_U	9.0	19.0
A_{IF}	10.0	20.0
A_{UF}	10.0	20.0
M_L	15.0	30.0

PRINTED CIRCUIT BOARD CONNECTOR

Table 2.11.1-5. Values of Failure Rate Modifier, π_P, for Number of Active Pins in a Connector

N	π_P	N	π_P
1	1.00	65	13.20
2	1.36	70	14.60
3	1.55	75	16.10
4	1.72	80	17.69
5	1.87	85	19.39
6	2.02	90	21.19
7	2.16	95	23.10
8	2.30	100	25.13
9	2.44	105	27.28
10	2.58	110	29.56
11	2.72	115	31.98
12	2.86	120	34.53
13	3.00	125	37.22
14	3.14	130	40.07
15	3.28	135	43.08
16	3.42	140	46.25
17	3.57	145	49.60
18	3.71	150	53.12
19	3.86	155	56.83
20	4.00	160	60.74
25	4.78	165	64.85
30	5.60	170	69.17
35	6.46	175	73.70
40	7.42	180	78.47
45	8.42	185	83.47
50	9.50	190	88.72
55	10.65	195	94.23
60	11.89	200	100.00

Π_P is a function of the number of active pins

$$\pi_P = e\left(\frac{N-1}{N_o}\right)^q$$

where $N_o = 10$

$q = 0.51064$

N = number of active pins

PRINTED CIRCUIT BOARD CONNECTOR

Table 2.11.1-6. Cycling Rate Factor π_K

Cycling Frequency (Matings/1000 Hours)	π_K
0 - 0.05	1.0
0.05 - 0.5	1.5
0.5 - 5.0	2.0
5.0 - 50.0	3.0
>50.0	4.0

A cycle is defined as the mating and unmating of a connector.

PRINTED CIRCUIT BOARD CONNECTOR

EXAMPLE

Connector with low cycling rates

Given: A two-piece printed circuit board connector (MIL-C-55302) with 50 active pins will be utilized in a ground fixed environment in which the connector is expected to be connected and disconnected once every 300 hours of operation. Pin size is 22 gage. Ambient temperature will be 25°C, and the expected load current will be 2.0 amperes.

Find: The failure rate of the connector.

Step 1. Calculate the operating temperature by adding the temperature rise in the connector to the ambient temperature, 25°C.

From Table 2.11.1-2, ΔT for 22 gage when 2.0 amperes are flowing = 3.6°C.

Operating temperature = ambient + heat rise.
Operating temperature = 25°C + 3.6°C = 28.6°C.

Step 2. From Table 2.11.1-3, λ_b is determined to be 0.00027 for 28.6°.

Step 3. From Table 2.11.1-4, π_E for ground environment is 4.0.

Step 4. From Table 2.11.1-5, π_P for 50 pins is determined to be 9.5.

Step 5. From Table 2.11.1-6, π_K for 3.0 matings/1000 hours is determined to be 2.0.

Step 6. The failure rate of the connector is determined by substituting the values determined into the failure rate equation:

$$\lambda_P = \lambda_b \; (\pi_E \times \pi_P \times \pi_K)$$

$$\lambda_p = 0.00027 \; (4 \times 9.5 \times 2)$$

$$\lambda_p = 0.02 \text{ failures}/10^6 \text{ hours.}$$

PRINTED CIRCUIT BOARD CONNECTOR

EXAMPLE

Connector with high cycling rate

Given: A two-piece printed circuit board connector with 96 active pins will be utilized in an airborne inhabited environment in a high performance aircraft in which the connector is expected to be connected and disconnected every 20 operating hours. Pin size is 22 gage. Ambient temperature will be 45°C, and the expected load current will be 2.5 amperes.

Find: The failure rate of the connector.

Step 1. Calculate the operating temperature by adding the temperature rise in the connector to the ambient temperature, 45°C.

From Table 2.11.1-2, ΔT for 22 gage when 2.5 amperes are flowing = 5.6°.

Operating temperature = ambient temperature + heat rise.
Operating temperature = 45°C + 5.6°C = 50.6°C.

Step 2. From Table 2.11.1-3, λ_b is determined to be 0.00048 for 50.6°C.

Step 3. From Table 2.11.1-4, π_E for airborne inhabited, high performance is 10.0.

Step 4. From Table 2.11.1-5, π_P for 96 active pins is 23.5.

Step 5. From Table 2.11.1-6, π_K for 50 cycles/1000 hours is 4.0.

Step 6. The failure rate of the connector is determined by substituting the values determined in the failure rate equation:

$$\lambda_P = \lambda_b (\pi_E \times \pi_P \times \pi_K)$$

$$\lambda_p = 0.00048 (10.0 \times 23.5 \times 4.0)$$

$$\lambda_p = 0.451 \times \text{failures}/10^6 \text{ hours.}$$